AD 414174

UNCLASSIFIED

63-4-5

USNRDL-TR-660
15 July 1963

IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES

by
S. Martin

U.S. NAVAL RADIOLOGICAL
DEFENSE LABORATORY

SAN FRANCISCO · CALIFORNIA · 94135

RADIATION EFFECTS BRANCH
R.S. Alger, Head

NUCLEONICS DIVISION
W.E. Kreger, Head

ADMINISTRATIVE INFORMATION

This work was accomplished under the Defense Atomic Support Agency Subtask 12.006 and is listed in the U.S. Naval Radiological Defense Laboratory Technical Program Summary for Fiscal Years 1963-1965 of 1 November 1962 under Program A-6, Problem 4, entitled "Ignition and Fire Propagation by Thermal Radiation." This study was supported through funds provided by the Defense Atomic Support Agency on Budget Project 99, Allotment 178/63, MIPR 5568-63.

AVAILABILITY OF COPIES

Requests for additional copies by agencies or activities of the Department of Defense, their contractors certified to DDC (formerly ASTIA), and other government agencies or activities should be directed to the Defense Documentation Center for Scientific and Technical Information, Cameron Station, Alexandria, Virginia.

All other persons and organizations should direct requests for this report to the U.S. Department of Commerce, Office of Technical Services, Washington 25, D.C.

Eugene P. Cooper

Eugene P. Cooper
Scientific Director

D.C. Campbell, CAPT USN
Commanding Officer and Director

ABSTRACT

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

SUMMARY

The Problem:

Both subkiloton-weapon air bursts and large-yield high-altitude bursts generate very brief pulses of thermal radiation. While theoretical considerations suggest that such short pulses are at least as efficient at producing incendiary effects as the longer duration pulses from more conventional detonations, supporting experimental evidence is meagre. Therefore, the problem was to measure radiant exposures for the sustained ignition of cellulosic kindling fuels for pulses as short as 30 ms duration.

The Findings:

The results indicate that for very brief pulses of thermal radiation, the radiant exposures required for ignition are not strongly dependent on exposure duration. The results may be interpreted to indicate that pulses generated by sub-KT air bursts and megaton high altitude bursts are as efficient at igniting materials as the longer-duration pulses of nominal-yield air bursts and are significantly more efficient than megaton-yield air bursts. Further, the observation of near-explosive ablation of organic solids exposed to extreme levels of radiant power suggests that structural damage by impulsive loading may be an important consequence of the brief thermal pulse from very-high-altitude detonations of multimegaton weapons.

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

REPORT OF INVESTIGATION

INTRODUCTION

The current trend in weapons technology has brought about a renewed interest in the effects of very brief pulses of radiant energy. Air bursts of subkiloton-yield weapons and very-high-altitude detonations of large-yield weapons radiate the effective portion of their thermal energy in times of the order of tens to hundreds of milliseconds.[1,2] In order to assess the incendiary capabilities of these innovations, it is necessary to extend our knowledge of ignition behavior to shorter exposure times. This is a report of recent work at NRDL which attempts to provide such information based on results of exposures pushing to the limit of the carbon-arc, mechanical-shutter system (up to 100 cal $cm^{-2}sec^{-1}$ and down to 30 ms).

BACKGROUND

Most of the previous work done on thermal ignition has dealt with pulse durations representative of nominal-KT to MT range air bursts. In the early days, a large amount of data on ignition energies was collected using triangular and square-wave pulses of about 1-sec duration. More recently the effort in this field has taken two directions: (1) the detailed study of ignition behavior of an idealized kindling fuel, α-cellulose, in terms of the parameters of the exposure (including its duration) and the properties of the fuel[3,4,5] and (2) the direct measurement of radiant exposure values for the ignition of specific kindling fuels exposed to pulses accurately simulating the time-irradiance characteristics of the thermal radiation from KT and MT air bursts.[6,7] For the most part, these studies utilized square-wave exposures measured in seconds (seldom less than 1/2 sec) and simulated weapon pulses of at least 2 sec duration (the time during which 80 percent of the total energy is delivered).

The work at NRDL, a generalized treatment of ignition behavior,[3,4] led to the following conclusions (appropriate to short pulses):

1. For pulses shorter than a certain value, which is proportional to the square of the thickness of the fuel and inversely proportional to the thermal diffusivity, the radiant exposure required for sustained ignition is approximately constant.

2. The square-wave pulse and the air-burst-weapon pulse generate the same ignition phenomena, only when the irradiance level of the square wave is about one third of the peak irradiance of the weapon pulse.

3. For short pulses, the characteristic pulse of the air burst is more efficient (i.e., it ignites celluloseic fuels with about 30 percent less delivered energy) than the square-wave input.

Recent studies of the pyrolysis phase of the ignition process[8,*] shed some light on what is to be expected as exposure durations are made increasingly shorter. It has been shown[8] that intensely irradiated cellulose ignites, but is not necessarily sustained, when the temperature

* Two USNRDL technical reports will be published soon dealing with the kinetics and volatile products of the pyrolysis reactions in thermally irradiated cellulose.

of the exposed surface reaches a fixed value (believed to be in excess of 600°C) and that the incident energy required for ignition is inversely proportional to the irradiance level and independent of the thickness. At about this point, the solid surface commences to ablate rapidly and shortly thereafter attains to a steady-state ablation rate and temperature profile. The steady-state ablation rate is proportional to the irradiance level and the total amount ablated is proportional to the radiant exposure. Sustained ignition is thought to occur when the temperature of the back surface of the material rises to some 200-300°C. Accordingly, the amount of unablated material remaining at the onset of sustained ignition is inversely proportional to the irradiance level and independent of the original thickness.

If the irradiance level is very high (in keeping with very short exposure durations), the overall energy requirement of the process described will be dependent primarily on the thickness (actually the product of thickness and volumetric heat capacity) of the material and independent of exposure duration. This can be seen most readily by considering the following hypothetical example.

A dark opaque cellulosic solid having typical thermal properties, when exposed to 100 cal $cm^{-2} sec^{-1}$, ignites spontaneously about 6 ms after the exposure begins. The temperature profile at this instant is very steep near the surface. Temperature of active pyrolysis extend into the material less than 0.001 in.

The material has already begun to ablate, of course, and some 10 ms later the process is a steady-state one with an ablation rate of roughly 0.001 in. every 10 ms (about 0.2 cm sec^{-1}). The steady-state temperature profile, though not as steep as the transient profile, is steep enough so that by the time the back surface temperature has risen to a point capable of sustaining the ignition, the front surface has moved to within a few thousandths of an inch of the back surface.

Since the amount ablated is proportional to the radiant exposure, the radiant exposure required for sustained ignition should be proportional to the original thickness less the little bit remaining. The difference (i.e., the energy required to ablate away the remaining material) becomes a less significant fraction of the whole for thicker materials at any irradiance and for higher irradiances on a material of given thickness.

EXPERIMENTAL

The modified 36 in. paraboloidal mirror, carbon-arc source[9] was used to provide the radiant energy. This source is capable of delivering irradiance levels of about 100 cal $cm^{-2}sec^{-1}$ uniform to ±5 percent over a circular area of 3/8 in. diameter. It is equipped with a high speed, air-driven shutter[10] which has an opening time (and closing time) of 3 ms. Exposure times as short as 20 ms can occasionally be achieved by the shutter, but 30 ms exposures are more usual. Fig. 1 is an oscilloscopic trace of a phototube's response to a 29-ms pulse (time measured between the half power points). For very short exposures, the pulse is more of a trapezoidal wave than a square wave.

To measure times of exposure as short as these, it was necessary to resort to a phototube circuit with a fast counter-timer read-out. As shown in Fig. 2, an exposure aperture (the same one used in previous studies) was modified in such a way as to allow exposure of a sample and simultaneous measurement of exposure duration. The accuracy of the timer count was verified on several preliminary trials by comparing it to the pulse width as measured by the timing phototube and by another phototube which viewed the pulse through the exposure aperture. The phototube outputs were displayed on an oscilloscope with accurately calibrated time scale. An example of the comparison is shown in Fig. 3.

The procedure followed was the one used in earlier investigations. The samples, black α-cellulose, newspaper and kraft corrugated board, were exposed to irradiance levels of 50,75 and 100 cal $cm^{-2}sec^{-1}$. The exposure duration was varied, reducing it when the previous sample ignited and increasing it when a sample failed to ignite, until the threshold value was determined as precisely as the system allows. Then the irradiance level was measured using the Mark VI, Mod 2 calorimeter.[11]

RESULTS

The measured exposure durations and computed radiant-exposure values for the sustained ignition of each of the materials exposed are listed in Table 1. Grossly considered, the radiant exposures required for ignition are relatively constant over times of exposure of such brevity. There is a small but significant (and consistent) upward trend toward higher irradiances and shorter exposure times. The data are plotted in Figs. 4 and 5 to show their agreement with previous results.[3]

All samples which failed to sustain ignition after being given exposures corresponding to the threshold of sustained ignition were drastically reduced in thickness in the area exposed. As suggested

TABLE 1 SQUARE-WAVE PULSE IGNITION VALUES

Description	Optical Absorptivity	Thickness (cm)	(mils)	Density (gm cm^{-3})	Irradiance (cal cm^{-2}sec^{-1})	Duration (m sec)	Radiant Exposure (cal cm^{-2})
Black α-cellulose No. 4090	0.9	0.012	5	0.62	50	62	3.1
					75	47	3.5
					100	35	3.5
Black α-cellulose No. 4091	0.9	.017	7	.64	50	98	4.9
					75	78	5.8
					100	53	5.3
Black α-cellulose No. 4092	0.9	.024	9	.65	50	140	7.0
					75	105	7.9
					100	78	7.8
Black α-cellulose No. 4093	0.9	.027	11	.67	50	160	8.0
					75	125	9.4
					100	95	9.5
Black α-cellulose No. 4094	0.9	.033	13	.68	50	210	10.5
					75	160	12.0
					100	122	12.2
Black α-cellulose No. 4095	0.9	.054	21	.67	50	380	19.0
					75	280	21.0
					100	220	22.0
Black α-cellulose No. 4096	0.9	.078	31	.68	50	606	30.3
					75	454	34.0
					100	386	38.6
Newspaper, darkest areas	0.8	.008	3	.62	50	42	2.1
					75	33	2.5
					100	28	2.8
Newspaper, half-tone areas	0.6	.008	3	.62	50	60	3.0
					75	40	3.0
					100	33	3.3
Newspaper, text areas	0.6	.008	3	.62	50	80	4.0
					75	60	4.5
					100	50	5.0
Newspaper, unprinted	0.35	.008	3	.62	50	110	5.5
					75	60	4.5
					100	55	5.5
Kraft fibre board, 200-lb. corrugated first thickness only	0.7	.032	13	.66	50	260	13
Kraft fibre board, 200-lb. corrugated, total thickness					50	~1200	~60
					75	~1300	~100
					100	1350	135

earlier, the remaining thickness was independent of the original thickness. The remaining thickness of several such samples exposed to 100 cal $cm^{-2}sec^{-1}$ was measured with a micrometer and found to be 0.002±0.0002 in. From this, knowing the exposure duration and the original thickness, it is possible to calculate the overall ablation rate. Table 2 illustrates how these estimates were obtained and lists their values. Internal agreement is good and the agreement with weight loss measurements at lower irradiances* is satisfactory (0.17 cm/sec calculated from 1 mg/cal weight loss assuming a density of 0.6 gm/cm^3).

TABLE 2 ABLATION RATE AT 100 CAL $CM^{-2}SEC^{-1}$

Description	Original Thickness (cm)	Final Thickness (cm)	Thickness Ablated (cm)	Duration (m sec)	Rate ($cm\ sec^{-1}$)
Black α-cellulose, No. 4090	0.012	0.005	0.007	35	0.2
Black α-cellulose, No. 4091	.017	.005	.012	53	.23
Black α-cellulose, No. 4092	.024	.005	.019	78	.24
Black α-cellulose, No. 4093	.027	.005	.022	95	.23
Black α-cellulose, No. 4094	.033	.005	.028	122	.23
Black α-cellulose, No. 4095	.054	.005	.049	220	.22
Black α-cellulose, No. 4096	.078	.005	.073	386	.19

* Unpublished data - see footnote on page 2.

DISCUSSION OF RESULTS AND CONCLUSIONS

These results completely substantiate the contention that for very short pulses the radiant exposures required for sustained ignition are not strongly dependent upon exposure duration. Actually, there is a gradual increase in the threshold radiant exposure going to shorter exposures, but this is probably less than a factor of two over an order of magnitude change in time, i.e., Q varies as about $t^{-1/4}$, where Q is radiant exposure and t is exposure duration. The reason for this upward trend is not immediately obvious. It probably is a reflection of the overall endothermicity of the ablation process which plays an increasingly greater role at the higher irradiance levels. It may be a result of the system being overdriven, that is, the overall process becoming reaction rate rather than heat diffusion controlled with consequent higher than "normal" temperatures associated with each subprocess. We are currently making surface temperature measurements as a function of time during exposure in an attempt to answer some of these questions.

Some difficulty was encountered in detecting the onset of sustained flaming at the 100 cal $cm^{-2}sec^{-1}$ level. Transient flaming occurs almost immediately after the exposure begins and, throughout the exposure, profuse flames jet out as much as a foot in front of the exposed surface. However, unless the exposure continues until the material is ablated away almost completely, sustained flaming fails to occur. An exposure lasting 10-20 ms longer does ablate the material away completely and, consequently, there is nothing left in the exposed area to sustain the flame. Flames do persist in the remaining material peripheral to the spot, but this kind of behavior is characteristic of the spot geometry of exposure and is not generally pertinent to exposure in the unapertured radiation field of a nuclear detonation. With still shorter pulse of higher irradiance, there arises a serious question of the significance of the sustained flaming threshold in an isolated fuel element.

Of course, if the fuel element is partially shadowed, then it is entirely reasonable to expect it to act just as these samples did. And, moreover, in a fuel bed where one fuel element shades its neighbor and is frequently located nearby in such a position that it is subsequently bathed in the flames of its neighbor, it is reasonable to expect that not only will flames persist, but also the interaction will markedly reduce the required radiant exposure. Even a single fuel element might exhibit such behavior if it is geometrically complex, e.g., a crumpled sheet of newspaper.

There is another effect of exposure of organic solids to very high levels of radiant power. During the course of the experimental work, a detectable mechanical impulse associated with the ablation process was observed. At radiant power levels, an order of magnitude greater than those used here, it may be possible to generate peak overpressures which would be large enough to cause structural damage to buildings. It is noteworthy that this effect is entirely independent of the thickness of the exposed material.

Both newspaper and kraft corrugated board exhibited some anomalous behavior at the high irradiances and short exposures used. With more conventional inputs, newspaper behaves as though it were made up of three parts; unprinted, medium printed (text and half-tone), and dark printed (headlines and "blacks" of pictures). The darkest parts, having the highest absorptivity, ignite with the least radiant exposure. If they constitute a significant area of the exposed sheet, they probably govern the ignition of the whole newspaper. The text and half-tone areas require more thermal input to ignite than the dark areas, and the unprinted areas require the most. The text areas make up the bulk of the newspaper and for this reason may be of major concern. However, at the short exposure times of this study, the text areas acted as though they were made up of two independent, noninteracting parts--the printed and the unprinted areas. The printed areas burned through at radiant exposure levels corresponding to those for sustained ignition of the large dark areas (headlines and pictures) of the paper, but failed to cause sustained ignition of the whole sample. It took radiant exposures nearly as large as those required for the unprinted borders of the newspaper to cause sustained ignition of the text areas. It is concluded that newspaper will sustain ignition for square-wave exposures of 2 to 5 cal cm^{-2} delivered in 50 to 100 ms, depending upon the amount and kind of printing. By way of contrast, even the darkest areas are expected to require some 20 to 30 cal cm^{-2} to sustain flame after exposure to a 10-MT air burst.[12]

With longer duration exposures, kraft corrugated board acts as though it were a composite fuel whose ignition behavior is governed by the first (exposed) layer of the corrugation. While, in this study of short exposures, the first layer did ignite as expected, it was unable to induce the sustained burning of the whole. It is believed, however, that this is due to conduction of heat away from the ignited area by the bulk of unexposed material surrounding it rather than a result characteristic of short pulses. A "cardboard" box exposed over one whole surface would very probably sustain ignition after exposure to a brief pulse of some 15 to 20 cal cm^{-2} as shown by the data in Table 1 for the first thickness.

It was stated earlier that for short exposures, the characteristic pulse of a nuclear weapon air burst is more efficient at igniting materials than the corresponding square-wave exposure . While there is no direct evidence along these lines for the case of very brief exposures, it seems quite likely from the nature of the ignition curves for the two types of input that the relationship holds here as well. Recognizing the current state of uncertainty about pulse shapes from high-altitude detonations of large weapons and low-altitude detonations of sub-kiloton weapons, we can conclude only that radiant exposures for ignition by such brief pulses may be less than those reported here but are probably greater than two thirds of these values.

REFERENCES

1. Reed, J. W., Gauvin, H. P., Cahill, J. P., Grenier, J. W., Baker D. J., and Stair, A. T., Jr., "Thermal Radiation From Low-Yield Nuclear Bursts" (U); Project 8.8, Operation HARDTACK, WT-1675, AFCRL, January 1962, Secret Restricted Data.

2. Jenkins, R. J., Inn, E. C. Y., Parker, W. J., and Rudkin, R. L., "Spectral Irradiance History of the Three High-Altitude Shots of Operation HARDTACK" (U); USNRDL-TR 333 (AFSWP 1133), March 1959, Secret Restricted Data.

3. Butler, C. P., Martin, S., and Lai, W., "Ignition of Alpha Cellulose by Square-Wave Exposure," USNRDL-TR 135 (AFSWP-906), November 1956, Unclassified.

4. Martin, S., and Lai, W., "Ignition of Alpha Cellulose by Pulses Simulating Nuclear Weapon Air Bursts," USNRDL-TR 252 (AFSWP 1082), May 1958, Unclassified.

5. Martin, S., Lincoln, K. A., and Ramstad, R. W., "Influence of the Moisture Content and Radiant Absorptivity of Cellulosic Materials on Their Ignition Behavior," USNRDL TR 295 (AFSWP 1117), December 1958, Unclassified.

6. Bruce, H. D., and Downs, L. E., "Ignition of Newspaper with Variations in Moisture Content and Pulse Time," FPL Technical Report (AFSWP-1099), October 1958, Unclassified.

7. Bracciaventi, J., and DeBold, F., "Critical Radiant Exposures for Persistent Ignition of Cellulosic Target Complex Materials," NML Technical Report (DASA 1194), July 1960, Unclassified.

8. Martin, S., and Ramstad, R. W., "Temperature Profiles in Thermally Irradiated Cellulose Accompanying its Spontaneous Ignition," USNRDL-TR 353 (DASA 1142), May 1959, Unclassified.

9. Butler, C. P., "High Intensity Carbon-Arc Sources for Thermal Radiation Studies," USNRDL-TR 453 (AFSWP-798), July 1955, Unclassified.

10. Day, R. P., Hopton, R. L., and Schmidt, A. C., "A High-Speed Air-Driven Shutter for Controlling Exposures to a Convergent Beam of High-Intensity Thermal Radiation," Rev. Sci. Instruments, 25, 654 (1954).

11. Broido, A., and Willoughby, A. B., "Measurement of Intense Beams of Thermal Radiation," Journ. Opt. Soc. Am., 48, 344 (1958).

12. Martin, S., and Broido, A., "Thermal Radiation and Fire Effects of Nuclear Detonations," USNRDL-TR 652 and DASA 1376 (1963).

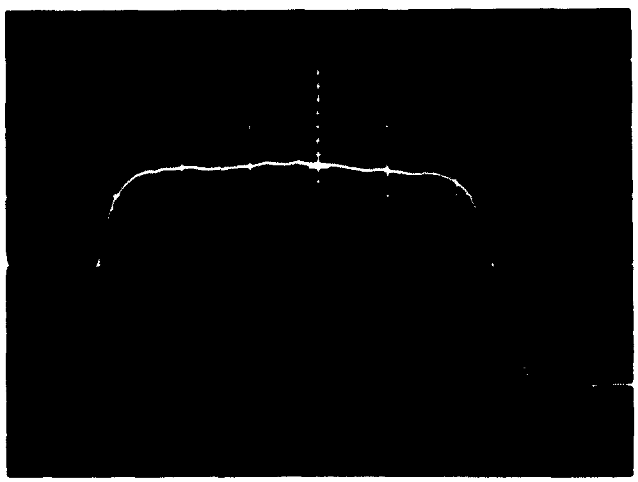

Fig. 1 Oscilloscope Trace of 29 ms Horizontal Scale Pulse. Horizontal Scale - 5 ms/cm.

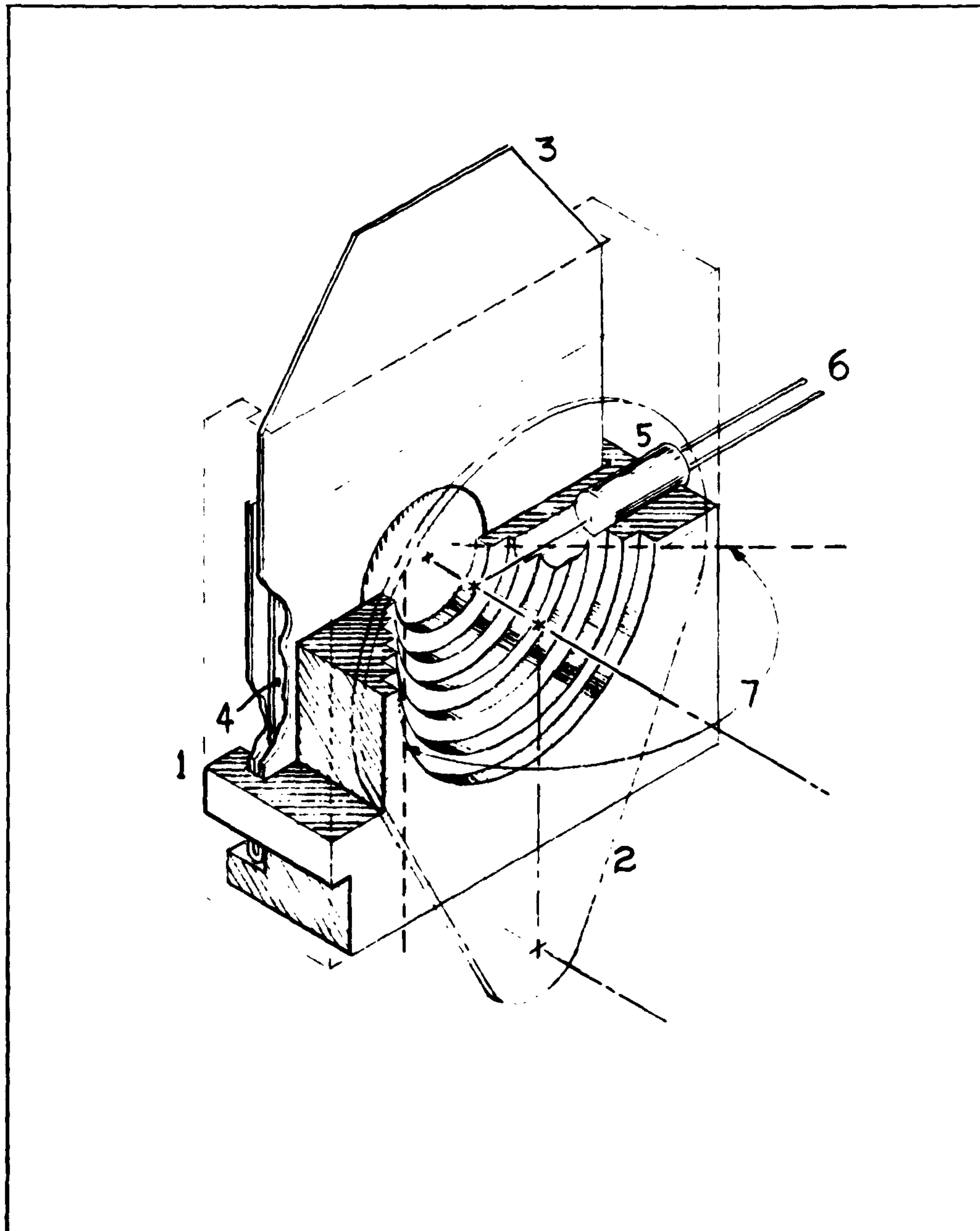

Fig. 2 Arrangement of Timing Phototube in Exposure Aperture

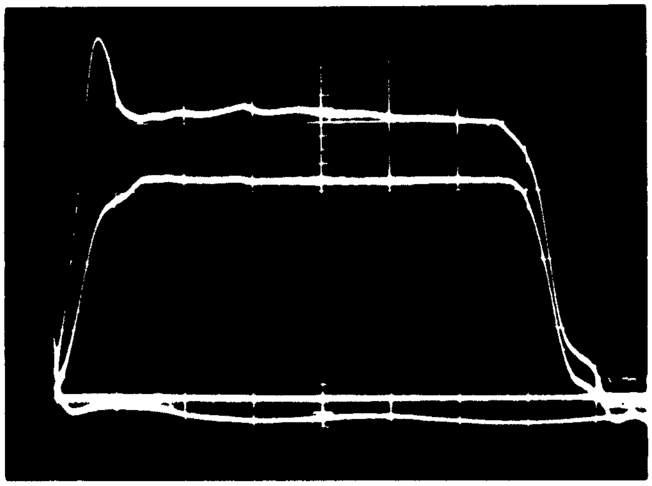

Fig. 3 Comparison of Response of Timing Phototube to Pulse as Viewed through Aperture.

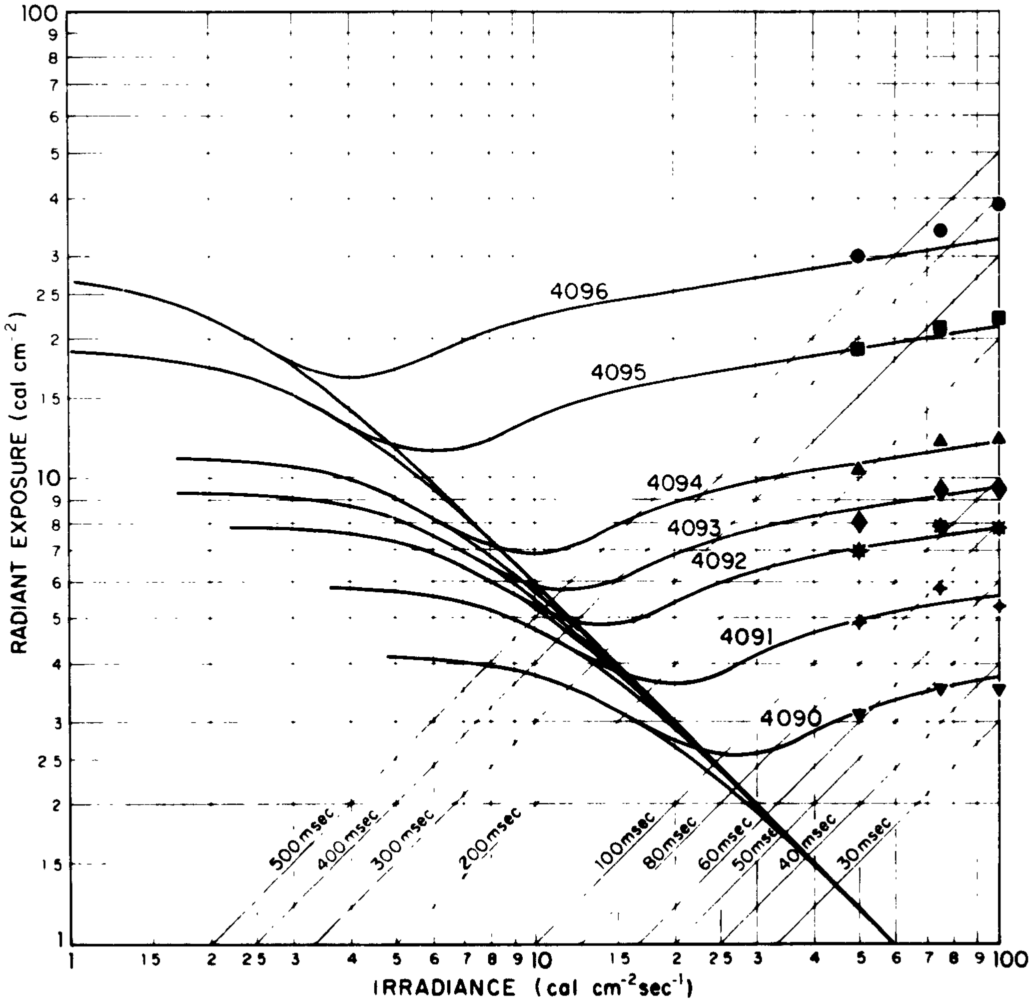

Fig. 4 Ignition of Alph-Cellulose. Curves are taken from previous investigations (Reference 4 and 5) and have been extrapolated to fit new data, retaining the proportionality between radiant exposure and thickness. The rapidly descending portions of the curves are thresholds of transient ignition. (For description of materials see Table 1).

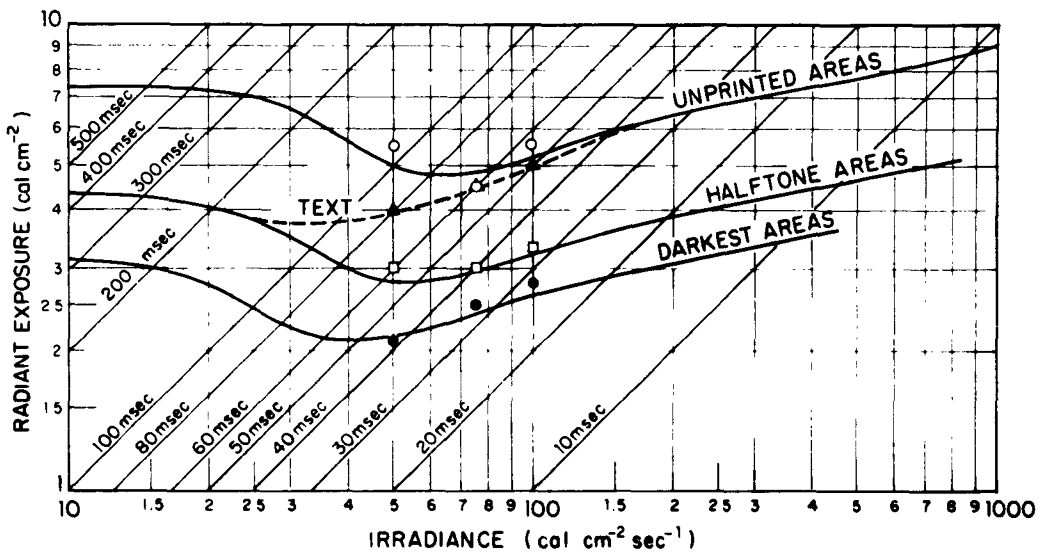

Fig. 5 Ignition of Newspaper Curves are Derived from Figure 4 using the principles described in Reference 5 to account for the different optical absorptivities of the various parts of the newspaper (See Table 1). Symbols indicate: O-unprinted areas; △-text; □-half-tone areas; ●-darkest areas.

Physics
DASA

INITIAL DISTRIBUTION

Copies

NAVY

1	Chief, Bureau of Ships (Code 320)
3	Chief, Bureau of Ships (Code 210L)
1	Chief, Bureau of Ships (Code 423)
2	Chief of Naval Weapons
1	Chief of Naval Operations (OP-07T)
2	Chief of Naval Operations (OP-75)
1	Chief of Naval Operations (OP-03EG)
1	Chief, Bureau of Medicine & Surgery, Special Weapons Def. Div.
1	Chief, Bureau of Supplies & Accounts
1	Chief, Bureau of Yards & Docks (D-440)
1	Chief, Bureau of Yards & Docks (Code 42)
1	Chief, Bureau of Yards & Docks (Code 50)
1	Chief of Naval Research (Code S11)
1	Chief of Naval Research(Code 104)
1	Office of Naval Research (Code 422)
3	Director, Naval Research Laboratory (Code 2021)
1	CO, Office of Naval Research Branch SF.
10	Office of Naval Research, FPO, New York
1	CiC, U. S. Pacific Fleet, FPO, San Francisco
1	CiC, U. S. Atlantic Fleet, Norfolk
1	Commandent of the Marine Corps (Code AO3H)
1	CO, Air Development Squadron 5, VX5, China Lake
1	Commander, U. S. Naval Ordnance Lab, White Oak, (EE Div)
1	Commander, U. S. Naval Ordnance Lab, White Oak, (R Div)
1	Commander, U. S. Naval Ordnance Test Station
1	CO, U. S. Naval Medical Research Institute
1	CO, U. S. Naval Air Development Center, (NAS Librarian)
1	Director, U. S. Naval Research Lab. (Cass)
1	Commander, New York Naval Shipyard (Dir. Materiel Lab.)
1	CO & Dir., U. S. Naval Electronics Lab, San Diego
1	CO., U. S. Naval Development Center
1	OiC, U. S. Naval Supply Research & Development Facility
1	CO, Naval Medical Field Research Laboratory, Camp Lejeune
1	CiC, Pacific, Fleet Post Office, S. F.

1 CO, U. S. Naval Schools Command, Treasure Island
1 Director, Marine Corps Landing Force Development Center
1 U. S. Naval Postgraduate School, Monterey
2 CO, Nuclear Weapons Training Center, Norfolk (Nuc. Warfare Dept.)
2 CO, Nuclear Weapons Training Center, San Diego
1 CO, U. S. Naval Damage Control Training Center, Phila. (ABC Def. Course)
1 President, U.S. Naval War College

ARMY

1 Office of Chief of Research and Development (Atomic Office)
1 Chief of Research and Development (Life Science Div.)
1 Deputy Chief of Staff for Military Operations (CBR)
1 Deputy Chief of Staff for Military Operations (SW&R)
1 Chief of Ordnance (ORDTN)
1 Chief Signal Officer, Combat Dev & Ops Div. (SIGCO-4)
1 Chief of Engineers (ENGMC-EB)
1 Chief of Engineers (ENGMC-DE)
1 Chief of Engineers (ENGCW-Z)
1 Chief of Engineers (ENGNB)
1 CO, Transportation Research Command (Tech Info Div.)
1 CG, Army Materiel Command (AMCRD-DE-NE)
1 CG, Ballistic Research Laboratories
1 U. S. Army Edgewood Arsenal
1 Chief Chemical Officer
1 CO, U. S. Army CBR Combat Dev Command Ft. McClellan
1 Commandant Chemical Corps Schools (Library)
1 CO, Chemical Research and Development Laboratories
1 Chief of Transportation (Military Planning & Intelligence Div.)
1 The Quartermaster General (R&D Div.)
1 Commander, Nuclear Defense Laboratory
1 President, U. S. Army Infantry Board
1 CG, Aberdeen Proving Ground
1 CG, U. S. Army Chemical Corps, R&D Command
1 President, U.S. Army Air Defense Board
1 CO, Army Medical Research Lab.
1 Director, Walter Reed Army Medical Center
1 Commandant, Walter Reed Army Institute of Research
1 President, U.S. Army Artillery Board
1 CG, Combat Developments Command (CDCMR-V)
1 CG, Quartermaster Res and Eng Command
1 Director, Special Weapons Development, Hq. CONARC
1 Hq., Dugway Proving Ground
3 The Surgeon General (MEDNE)
1 CO, Army Electronic Res. and Dev. Agency
1 CO, Engineer Res. and Dev. Laboratory

1	Director, USACDS Nuclear Group
1	CO, Army Office Ordnance Research
1	Director, Waterways Experiment Station (Library)
1	Director, Operations Research Office, Bethesda
1	CG, Quartermaster R&D Command (CBR Liaison Officer)
1	CG, Mobility Command
1	CG, Munitions Command
1	CO, Watertown Arsenal
1	CG, Frankford Arsenal
1	Commandant, U.S. Army Command and General Staff College
1	Commandant, U.S. Army Air Defense School
1	Commandant, U. S. Army Armored School
1	Commandant, U.S. Army Artillery & Missile School
1	Commandant, U. S. Army Infantry School
1	Superintendent, U. S. Military Academy
1	Commandant, U. S. Army Ordnance & Guided Missile School
1	Commandant, U. S. Army Chemical School
1	Commandant, U. S. Army Signal School
1	Commandant, Engineer School
1	Medical Field Service School (Stimson Library)

AIR FORCE

1	Assistant Chief of Staff Intelligence (AFCIN-3B)
5	CG, Aeronautical Systems Division (ASAPRD-NS)
1	Directorate of Civil Engineering (AFOCE-ES)
1	Director, USAF Project Rand
1	Commandant, School of Aerospace Medicine, Brooks AFB
1	Office of the Surgeon (SUP3.1) Strategic Air Command
1	Director, Air University Library, Maxwell AFB
2	Commander, Technical Training Wing, 3415th TTG
1	Commander, Electronic Systems Division (CRZT)
1	Hq., U. S. Air Force (AFTAC)
1	Deputy Chief of Staff, (Operations Analysis)
1	Deputy Chief of Staff, (War Plans Div.)
1	Director of Research & Development DCS/D (Guidance & Weapons Div.)
2	Air Force Intelligence Center (ACS/I AFCIN-3V1)
1	The Surgeon General (Bio Def Br., Prov Med Div.)
1	CG, Strategic Air Command (OAWS)
1	CG, Tactical Air Command (Doc Sec Branch)
1	CG, Air Defense Command (ADLDC-A)
1	CG, Air Proving Ground Command (PGTRIL)
1	CG, Air Force Cambridge Research Center (CROQST-2)
1	CG, Air Force Weapons Laboratory (Tech Info Office)

OTHER DOD ACTIVITIES

3	Chief, Defense Atomic Support Agency (Library)
1	Commander, FC/DASA, Sandia Base (FCDV)
1	Commander, FC/DASA, Sandia Base (FCTG5, Library)
1	Commander, FC/DASA, Sandia Base (FCWT)
2	Office of Civil Defense, Washington
2	Civil Defense Unit, Army Library
20	Defense Documentation Center
1	AEC Scientific Representative, France
1	AEC Scientific Representative, Japan
1	Director, Armed Forces Radiobiology Research Institute
1	Director, Weapons Systems Evaluation Group
1	Office of the U.S. National Military Representative SHAPE
1	Director of Defense Res & Eng (Tech Lib)
1	Commandant, Armed Forces Staff College
1	Los Alamos Scientific Lab (Report Librarian)
1	CG, Army Material Command
1	CO, Diamond Ordnance Fuze Lab. (Vulnerability Branch 230)
1	CG, U. S. Army Electronic Proving Ground (Tech Lib)
1	The Research & Analysis Corp
1	Director, Special Projects, ND. (SP-43)
1	CO & Dir., U. S. Naval Civil Eng Lab. (Code L31)
1	Director, National Aeronautics and Space Administration
1	Director, Advanced Research Projects Agency (DEFENDER)
1	Chief, Fire Protection Section, National Bureau of Standards
1	National Academy of Science (National Research Council)
1	DCA (NMCSSC)

AEC ACTIVITIES AND OTHERS

1	Aerojet General, Azusa
1	Aerojet General, San Ramon
1	Allis-Chalmers Manufacturing Co, Milwaukee
1	Allis-Chalmers Manufacturing Co, Schenectady
1	Allis-Chalmers Manufacturing Co, Washington
1	Allison Division - GMC
2	Argonne Cancer Research Hospital
10	Argonne National Laboratory
1	Armour Research Foundation
1	Atomic Bomb Casualty Commission
3	Atomic Energy Commission, Washington
4	Atomic Energy of Canada, Limited
4	Atomics International
2	Babcock and Wilcox Co.
2	Battelle Memorial Institute

2 Beers, Roland F. Inc.
1 Carnegie Institute of Technology
1 Chance Vought Aircraft Corporation
1 Chicago Patent Group (AEC)
1 Columbia University (Havens)
1 Columbia University (NYO-187)
1 Combustion Engineering, Inc.
1 Combustion Engineering, Inc. (NRD)
5 Defence Research Member
3 Du Pont Company, Aiken
1 Du Pont Company, Wilmington
1 Edgerton, Germeshausen and Grier, Inc. Las Vegas
1 Franklin Institute of Pennsylvania
1 Fundamental Methods Association
2 General Atomic Division
1 General Dynamics-Astronautics (NASA)
1 General Dynamics/Convair, San Diego (BuWeps)
1 General Dynamics, Fort Worth
2 General Electric Company, Cincinnati
1 General Electric Company, Pleasanton
6 General Electric Company, Richland
1 General Electric Company, San Jose
1 General Electric Company, St. Petersburgh
1 General Nuclear Engineering Corporation
1 General Scientific Corporation
1 Gibbs and Cox, Inc.
1 Goodyear Atomic Corporation
1 Holmes & Narver, Inc.
1 Hughes Aircraft Company, Culver City
2 Iowa State University
2 Jet Propulsion Laboratory
3 Knolls Atomic Power Laboratory
1 Lockheed - Georgia Company
1 Lockheed Missiles and Space Company (NASA)
2 Los Alamos Scientific Laboratory (Library)
1 Lovelace Foundation
1 Maritime Administration
1 Marquardt Corporation
1 Martin-Marietta Corporation
2 Massachusetts Institute of Technology
2 Midwestern Universities Research Association
1 Mound Laboratory
1 NASA, Langley Research Center
1 NASA, Lewis Research Center
2 NASA, Scientific and Technical Information Facility
1 National Bureau of Standards (Library)

2	National Bureau of Standards (Taylor)
1	National Lead Company of Ohio
2	Nevada Operations Office
1	New Brunswick Area Office
1	New York University (Benderson)
1	New York University (Richtmeyer)
1	Northeastern University
1	Nuclear Materials and Equipment Corporation
1	Nuclear Metals, Inc.
1	Office of Assistant General,General Councel for Patents
1	Pennsylvania State University
4	Phillips Petroleum Company
1	Power Reactor Development Company
3	Pratt and Whitney Aircraft Division
1	Princeton University (White)
1	Public Health Service, Las Vegas
1	Public Health Service, Montgomery
2	Public Health Service, Washington
1	Purdue University
1	Research Analysis Corporation
1	Rensselaer Polytechnic Institute
1	Sandia Corporation, Albuquerque
1	Sandia Corporation, Livermore
1	Space Technology Laboratories, Inc. (NASA)
1	Stanford University (SLAC)
1	Stevens Institute of Technology
1	Tennessee Valley Authority
1	Technical Research Group
1	Texas Nuclear Corporation
2	Union Carbide Nuclear Company (ORGDP)
5	Union Carbide Nuclear Company (ORNL)
1	Union Carbide Nuclear Company (Paducah Plant)
2	United Nuclear Corporation (NDA)
1	University of California, Los Angeles
2	U. of California Lawrence Radiation Lab. Berkeley
4	U. of California Lawrence Radiation Lab. Livermore
1	University of Puerto Rico
1	University of Rochester (Atomic Energy Project)
2	University of Rochester (Marshak)
1	University of Washington (Gabelle)
1	University of Washington (Rohde)
1	U.S. Geological Survey, Denver
1	U.S. Geological Survey, Menlo Park
1	U.S. Geological Survey, Naval Weapons Plant
1	U.S. Geological Survey, Washington
1	Western Reserve University (Major)

4	Westinghouse Bettis Atomic Power Laboratory
2	Westinghouse Electric Corporation (Rahilly)
1	Westinghouse Electric Corporation (NASA)
1	Yale University (Schultz)
1	Yale University (Breit)
1	Yankee Atomic Electric Company
25	Technical Information Extension, Oak Ridge

<u>USNRDL</u>

55	Technical Information Division

DISTRIBUTION DATE: 26 August 1963

Naval Radiological Defense Laboratory
USNRDL-TR-660
IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES by S. Martin
15 July 1963 30 p. tables illus. 12 refs.
UNCLASSIFIED

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness
(over)

1. Cellulose.
2. Paper.
3. Exposure.
4. Thermal radiation.
5. Ignition.
6. Flames.
7. Ablation.
8. Nuclear effects.
I. Martin, S.
II. Title.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-660
IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES by S. Martin
15 July 1963 30 p. tables illus. 12 refs.
UNCLASSIFIED

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness
(over)

1. Cellulose.
2. Paper.
3. Exposure.
4. Thermal radiation.
5. Ignition.
6. Flames.
7. Ablation.
8. Nuclear effects.
I. Martin, S.
II. Title.

UNCLASSIFIED

of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

UNCLASSIFIED

of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-660
IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES by S. Martin
15 July 1963 30 p. tables illus. 12 refs.
UNCLASSIFIED

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness

(over)

1. Cellulose.
2. Paper.
3. Exposure.
4. Thermal radiation.
5. Ignition.
6. Flames.
7. Ablation.
8. Nuclear effects.

I. Martin, S.
II. Title.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-660
IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES by S. Martin
15 July 1963 30 p. tables illus. 12 refs.
UNCLASSIFIED

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness

(over)

1. Cellulose.
2. Paper.
3. Exposure.
4. Thermal radiation.
5. Ignition.
6. Flames.
7. Ablation.
8. Nuclear effects.

I. Martin, S.
II. Title.

UNCLASSIFIED

of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

UNCLASSIFIED

of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-660
IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES by S. Martin
15 July 1963 30 p. tables illus. 12 refs.
UNCLASSIFIED

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness
(over)

1. Cellulose.
2. Paper.
3. Exposure.
4. Thermal radiation.
5. Ignition.
6. Flames.
7. Ablation.
8. Nuclear effects.

I. Martin, S.
II. Title.

UNCLASSIFIED

of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-660
IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES by S. Martin
15 July 1963 30 p. tables illus. 12 refs.
UNCLASSIFIED

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness
(over)

1. Cellulose.
2. Paper.
3. Exposure.
4. Thermal radiation.
5. Ignition.
6. Flames.
7. Ablation.
8. Nuclear effects.

I. Martin, S.
II. Title.

UNCLASSIFIED

of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-660
IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES by S. Martin
15 July 1963 30 p. tables illus. 12 refs.
UNCLASSIFIED

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness
(over)

1. Cellulose.
2. Paper.
3. Exposure.
4. Thermal radiation.
5. Ignition.
6. Flames.
7. Ablation.
8. Nuclear effects.
I. Martin, S.
II. Title.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-660
IGNITION OF CELLULOSIC KINDLING FUELS BY VERY BRIEF RADIANT PULSES by S. Martin
15 July 1963 30 p. tables illus. 12 refs.
UNCLASSIFIED

Radiant exposure values are reported for sustained flaming ignition of black α-cellulose, newspaper and kraft corrugated board exposed to constant-irradiance, thermal inputs of 30 ms duration and longer. The radiant exposure values are shown to be approximately proportional to the thickness
(over)

1. Cellulose.
2. Paper.
3. Exposure.
4. Thermal radiation.
5. Ignition.
6. Flames.
7. Ablation.
8. Nuclear effects.
I. Martin, S.
II. Title.

UNCLASSIFIED

of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

UNCLASSIFIED

of the exposed material and not strongly dependent on exposure duration for pulses this brief. The significance of sustained flaming ignition, relative to ablation effects, for pulses of very brief duration is discussed.

UNCLASSIFIED